Message encoding/decoding using chaotic pulsing semiconductor lasers

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Abstract: Chaotic communication using chaotic pulsing semiconductor lasers has been investigated. High-speed digital message has been encoded/decoded on a chaotic pulsing carrier. Good message hiding during transmission and message recovery at receiver has been observed.

OCIS codes: (060.4510) Optical communications; (140.1540) Chaos

Chaotic communication has recently attracted great interest because of its potential applications in secure communications and spread spectrum communications. Chaotic communication uses a noise-like broadband chaotic waveform as carrier. Optical chaotic communication using semiconductor lasers with optical feedback has been investigated, but the transmitted message is quite slow with a frequency of about 10 kHz [1]. Chaotic wavelength fluctuation generated by optoelectronic feedback has also been used to encode/decode messages [2]. The bit rate of the message is also slow because of the relatively long time required to change the wavelength of the laser rather than to change the intensity. High-speed optical chaotic communication has been achieved using fiber-ring lasers [3]. Unfortunately, this fiber-ring laser system has been found to be not secure enough and the message is easy to be decoded simply by analyzing the received signal [4]. Therefore, in order to accomplish secure communication with high bit rate, other highly nonlinear systems which can generate high-speed chaotic waveforms have to be investigated. In this paper, we report our results of high-speed message encoding/decoding using fast chaotic pulsing semiconductor lasers. The fast chaotic pulsing is generated by a semiconductor laser operated in a highly nonlinear region by the effect of delayed optoelectronic feedback. The chaotic pulsing has both chaoticly varying pulse intensities and pulse intervals.

The schematic experimental setup of the chaotic communication system using chaotic pulsing semiconductor lasers are shown in Fig. 1. In this setup, the transmitter laser has an optoelectronic feedback loop which drives the laser into chaotic pulsing at certain delay times through a route of quasiperiodicity [5]. The message $m(t)$ is encoded by chaotic additive encoding after the light comes out of the transmitter laser. On the receiver side, a receiver laser is driven by the signal from the transmitter. When the two lasers synchronize, the receiver laser can reproduce the chaotic pulsing output of the transmitter laser. Therefore, the message can be recovered by subtracting the reproduced chaotic waveform at the output of the receiver laser from the received signal, which is a combination of the chaotic waveform and the message. In an optical chaotic communication system, it is important that the message encoding is applied after the output of the transmitter laser so that when the receiver laser synchronizes and duplicates the output of the transmitter laser, it only reproduces the chaotic carrier. Otherwise, for example, if the message is directly current-modulated on the transmitter laser, the outputs of the transmitter laser and the synchronized receiver laser both have message included. Decoding is then unlikely for the lack of ability to reproduce the pure chaotic carrier.

With the optoelectronic feedback, the transmitter laser can be described by the following rate equations [5]:

$$\frac{dS}{dt} = -\gamma_c S + \Gamma g S \tag{1}$$

$$\frac{dN}{dt} = \frac{J}{ed}\left[1 + \xi y(t-\tau)\right] - \gamma_s N - gS \tag{2}$$

$$y(t) = \int_{-\infty}^{t} d\eta f(t-\eta)\left[\frac{S(\eta)}{S_0} + m(\eta)\right] \tag{3}$$

where S is the intracavity photon density, S_0 is the free-running intracavity photon density when the laser is not subject to the feedback, N is the carrier density, $y(t)$ is the feedback signal, m(t) is the encoded message, ξ is the dimensionless feedback parameter which corresponds to the strength of the feedback, and

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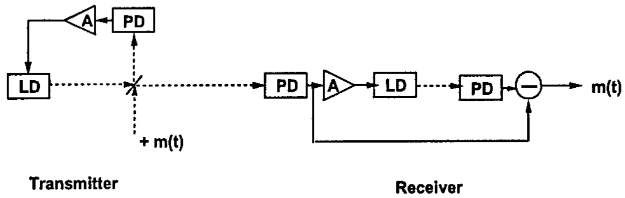

Fig. 1. Schematic setup of the chaotic communication system with chaotic pulsing semiconductor lasers. LD: Laser Diodes, PD: Photodetector, A: Amplifier.

τ is the feedback delay time. The nonlinear effect of the laser is included in the gain coefficient $g(N,S)$ which depends on both the intracavity photon density and the carrier density [6]. Other parameters of the transmitter laser are the cavity photon decay rate γ_c, the spontaneous carrier decay rate γ_s, the confinement factor of the laser waveguide Γ, the bias current density J, the electronic charge constant e, and the active layer thickness d. As the optoelectronic feedback is bandwidth-limited by the finite frequency response of the photodetector and the amplifier, $y(t)$ is the convolution integral of the fed back optical signal and the total response function of the feedback loop $f(t)$ [5].

The equations that describe the dynamics of the receiver laser are

$$\frac{dS'}{dt} = -\gamma_c S' + \Gamma g S' \tag{4}$$

$$\frac{dN'}{dt} = \frac{J}{ed}[1+\xi y'(t-\tau)] - \gamma_s N' - gS' \tag{5}$$

$$y'(t) = \int_{-\infty}^{t} d\eta f'(t-\eta)\left[\frac{S(\eta)}{S_0} + m(\eta)\right] \tag{6}$$

where each variable has the same meaning as the corresponding variable of the transmitter laser. The response function of the transforming circuit for the coupled signal from the transmitter to drive the receiver laser is $f'(t)$. Comparing Eqns. (3) and (6), we can see that the two lasers are actually driven by the same force when $f'(t) = f(t)$, which can be achieved by using identical photodetectors and amplifiers. Therefore, with the parameters of the transmitter and the receiver lasers all matched, chaotic communication through synchronized laser chaos is possible [7]. Seen from the rate equations, our transmitter and receiver lasers are identical even with the presence of the encoded message. As a result, the process of message encoding does not influence the quality of synchronization and there is no restriction on the message to be small compared with the chaotic carrier. Chaotic synchronization has been observed in this system and reported in Ref. 8. In the following, we report our experimental results on message encoding/decoding.

In the experiment, the two lasers are identical InGaAsP/InP single-mode DFB lasers with a wavelength at 1.3 μm. The photodetectors are InGaAs photodetectors (6 GHz bandwidth), and the amplifiers are Avantek SSF86 amplifiers (0.4 − 3 GHz bandpass). The message is generated by a comb generator. The optical output detected by the photodetectors is observed with a Tektronix TDS 694C digitizing sampling oscilloscope with a 3 GHz bandwidth and an up to 1×10^{10} Samples/sec sampling rate. The power spectra are measured with an HP E4407B spectrum analyzer.

Figure 2 shows the experimental result of the encoding/decoding of a stream of narrow pulses with 100 MHz repetition rate. The time series of the pulse encoding/decoding is shown in Fig. 2(a). The top trace is the received signal with message encoded. The second trace is the local receiver laser output, which synchronizes and duplicates the chaotic pulsing output of the transmitter laser. As the encoding scheme in our system is chaotic additive encoding, the message is recovered by subtracting the receiver laser output (the second trace) from the received signal (the top trace). The recovered message shows good quality of decoding as indicated by the recovered pulse train in the third trace, compared with the encoding message shown in the bottom trace as a reference. As of the chaotic pulsing characteristic of the output from our semiconductor laser with optoelectronic feedback, the encoding digital pulses can be hidden in the chaotic pulse stream very nicely. The power spectra of the pulse encoding and decoding are shown in Fig. 2(b), where the top trace is the power spectrum of the received signal, the middle trace is that of the receiver laser output, and the bottom trace is that of the encoding message. Shown in Fig. 2(b), the chaotic pulsing carrier has

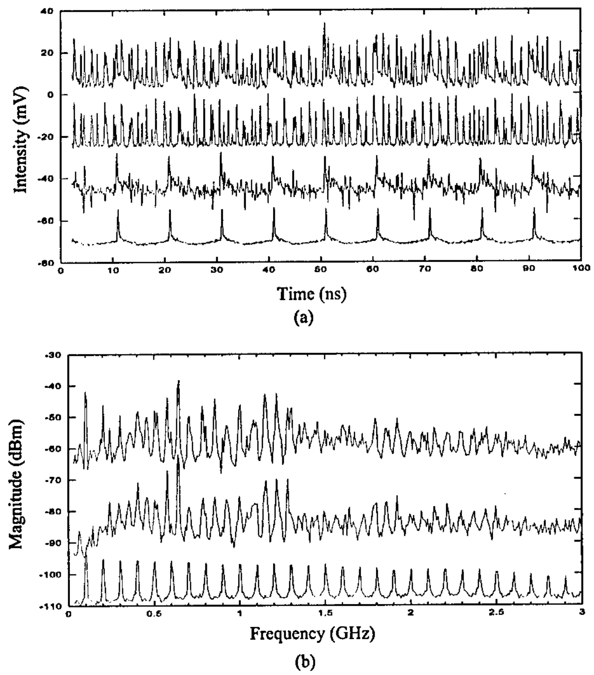

Fig. 2. Encoding/decoding of digital pulses with 100 MHz repetition rate. (a) Time series of received signal (top), receiver laser output (second), recovered digital message (third), and encoding message (bottom). (b) Power spectra of received signal (top), receiver laser output (middle) and encoding message (bottom).

a characteristic spectrum of broadband background with multiple spikes, while the power spectrum of the pulsing message also has multiple spikes. As a result, the encoding message can also be nicely hidden in the frequency domain by the chaotic pulsing carrier.

In conclusion, high-speed digital pulsing message has been successfully encoded and decoded in our chaotic pulsing system. The encoded message is also involved in the laser dynamics by the optoelectronic feedback loop, which not only drives the laser output to be more chaotic, but also embeds the message dynamically in the chaotic carrier. As the transmitter and the receiver lasers remain identical with the presence of message encoding, the two lasers synchronize at any time even with large and fast encoded messages. Therefore, the bit rate of the encoded message can possibly be as high as the repetition rate of the chaotic pulsing, which is about 600 MHz at present time. With even faster components, we can generate faster chaotic pulsing, with which the bit rate can be improved to multigiga bits per second.

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